US LHC Accelerator Research Program

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Quadrupole Model Magnet R&D

Alexander Zlobin, Fermilab
For BNL-FNAL-LBNL Accelerator Collaboration

Outline

IR Designs and Magnet Requirements

Challenges

Model Magnet R&D Strategy

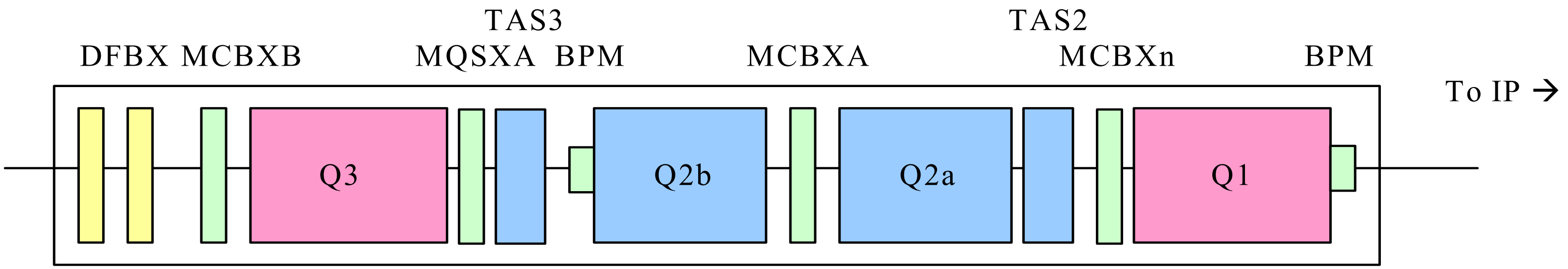
Conclusions

1st Generation LHC IRs

Baseline LHC inner triplets consist of single-bore, high-gradient quads based on NbTi superconductor.

Quadrupole parameters:

- 70 mm coil aperture
- 205 T/m nominal gradient with 20% margin
- 1.9 K operating temperature



2^{nd} generation Inner Triplet Design Options

Two fundamental inner triplet design approaches:

a) single-bore inner triplet design

b) dipole-first designs with double-bore quadrupoles

a) single-bore inner triplet design

Quadrupoles with largest possible aperture are required, to provide largest beam separation and accommodate the large β-max.

Preliminary analysis shows that the aperture limit for Nb_3Sn quads is 110 mm for the present operating field gradient of 205 T/m and 20% critical current margin.

2nd generation Inner Triplet Design Options

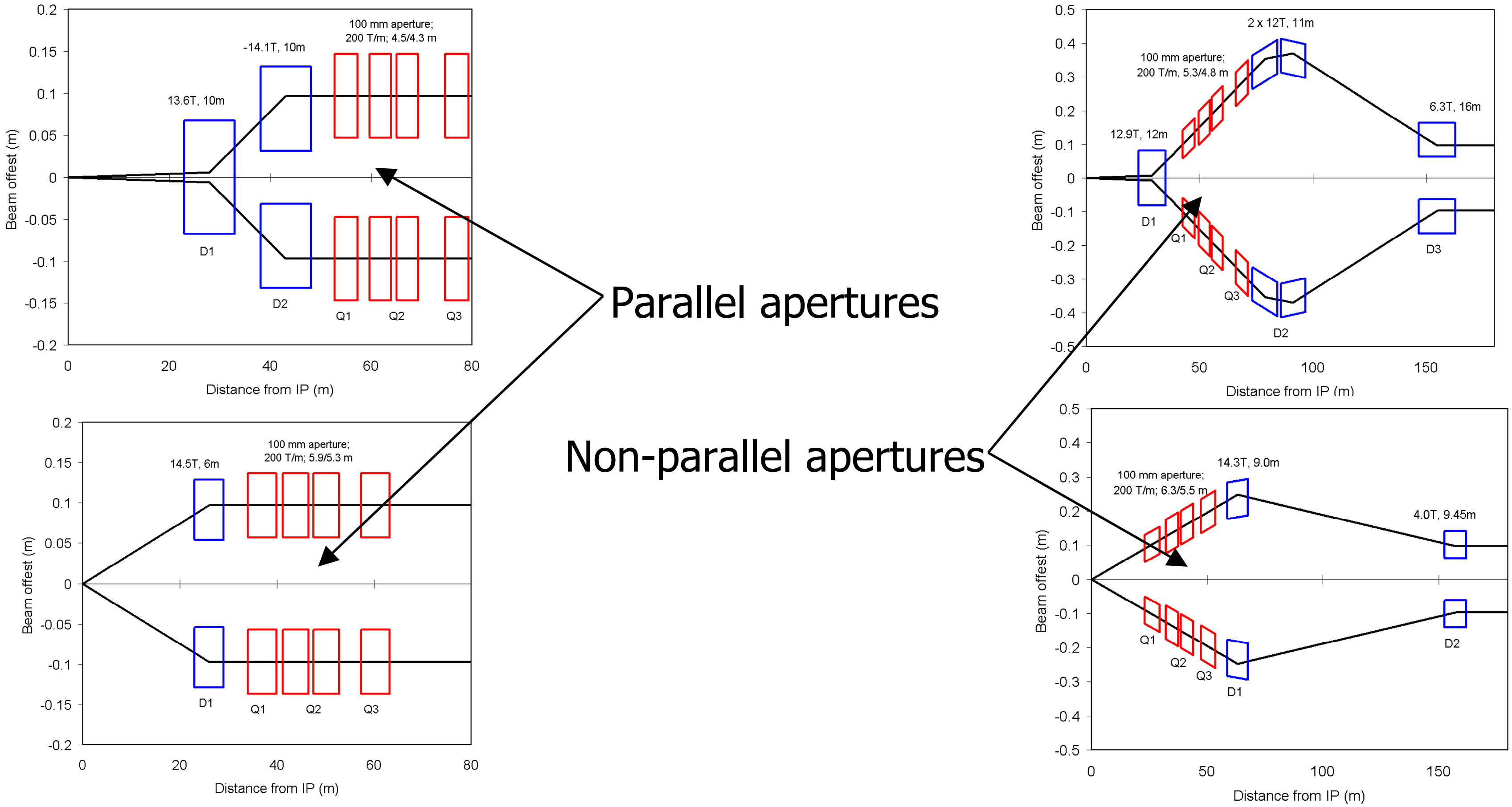
b) dipole-first designs with double-bore quadrupoles

For these IR designs there are two contradictory requirements for IR quads:

- Large β-max requires large aperture
- Twin-bore configuration limits aperture

Combination of these two requirements leads to the aperture size of double-bore quadrupoles of 100 mm.

Double-bore Inner Triplet Designs



Examples of 2nd generation LHC IR optics based on double-bore inner triplet with 100 mm quads.

Challenges

The operating gradient of 205 T/m => G_{max} = 250 T/m, in magnet bore 100-110 mm, push magnet parameters above the present state-of-the-art:

- Jc(12T,4.2K)>3 kA/mm^2 in the coil;
- the B_{max} in the coil at quench >15 T exceeding the level reached in Nb_3Sn accelerator magnets to date;
- the maximum stress in the coil, induced by Lorentz forces, reaches 100 MPa, approaching the level of stress which may cause significant degradation or even damage of brittle Nb_3Sn coils.

R&D Questions

R&D questions:

- What is the optimum aperture for single-bore and double-bore quads?
- What is the optimal design large-aperture Nb_3Sn quads?
- What are appropriate materials for operational conditions?
- Can magnets provide field of 15 T in the extreme radiation environment at very high luminosity?
- Can good field quality be maintained in magnets over the full operating range?
- How can the large heat deposition (few kW) be removed from the magnet cold mass for a tolerable cost?
- Are non-parallel axis double-bore quadrupoles feasible?

Most of these questions requires model magnet R&D.

Common Quadrupole and Dipole Features

Many of R&D issues are common to new IR dipoles and quadrupoles such as:

- Conductor issues (new Nb_3Sn high-J_c strands, stability, magnetization, degradation)
- Maximum field and field quality
- Mechanics and high-stress management
- Coil cooling and heat transfer to cryogenic system
- Quench protection
- Materials and components (high radiation insulation)
- Technology: react and wind approach

The tight connection and cross-talk of both magnet R&D directions is natural and will lead to the high efficiency of the whole program.

IRQ Magnet R&D Strategy

A success of the quadrupole development program is the key to any of the future IR design.

The parameters of the new IR quads have to be pushed to their extremes to provide the best performance of the new generation IRs.

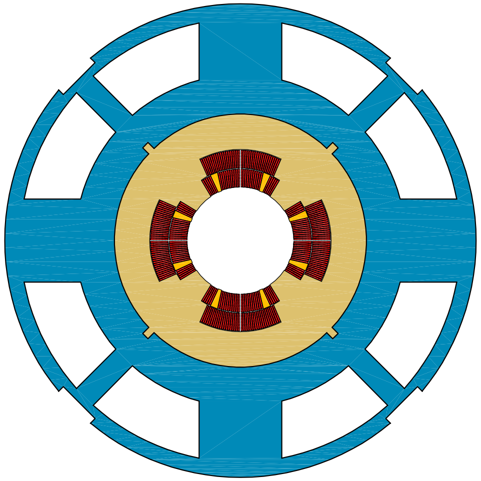
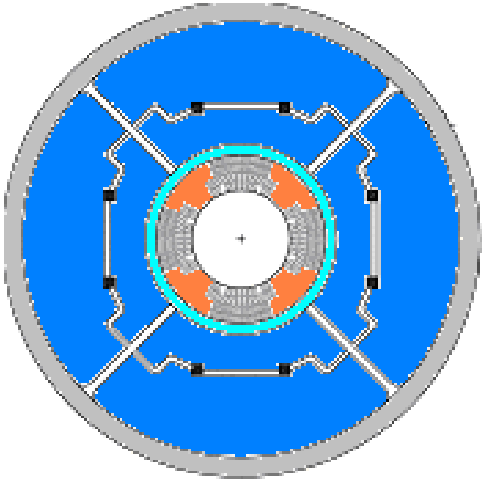
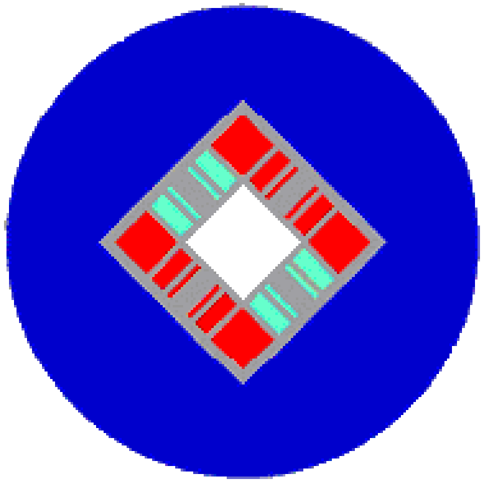
But the IR quadrupole design and parameters have to be realistic to accomplish the R&D in a finite time and be ready to replace the IR magnets in 2015.

Balance of these two requirements will drive the quadrupole model R&D program.

IRQ Conceptual Designs

Possible IR quadrupole conceptual designs for 2nd generation LHC IRs:

- coil design approaches - block vs. shell-type
- coil support structures - thick collar vs. shrinking cylinder
- iron design - optimization of the iron saturation effects and the longitudinal heat transfer in the magnet cold mass

Sequence of Model Magnets

We start IRQ model R&D in FY06 with simplified 1-m long models (2-layer design) in order to develop basic tooling and infrastructure and start basic technology development.

A series of short models will address the issues of magnet quench performance, field quality, mechanics, quench protection, reproducibility, long term performance, etc.

We will start studying length dependent effects with 4-m long coils, as soon as we achieve acceptable quench performance.

Model R&D will be followed by the construction of one or more prototypes containing all of the features required for use in the LHC.

Conclusions

The proposed R&D program is very challenging.

The budget profile does not allow starting extensive model testing before FY2006-2007.

Strong connection between the LARP magnet R&D program and the base High Field Magnet R&D programs is critical, in order to reduce risks and increase the probability of success.

Base magnet R&D programs for Nb_3Sn HFM should be able to demonstrate the possibilities and limitations for this technology during next couple of years.